A tool for analysis of costs on the manufacturing of the hull

Chapter · January 2018

2 authors, including:

José Manuel Gordo
University of Lisbon
82 PUBLICATIONS **685** CITATIONS

Some of the authors of this publication are also working on these related projects:

Block's manufactoring and Costs View project

Fairing & Forming View project

A tool for analysis of costs on the manufacturing of the hull

J.M. Gordo
Centre for Marine Technology and Ocean Engineering (CENTEC), Instituto Superior Técnico,
Universidade de Lisboa, Lisbon, Portugal

M. Leal
One Ocean, Lisbon, Portugal

ABSTRACT: It is presented a tool for the analysis of costs in the early stages of preliminary and detailed design in a shipyard. It was developed, within this study, a simple Excel worksheet that will calculate several aspects of the construction budget and expected building times by adding simple input data. The tool uses as example two case studies in different shipyards and may be easily modified in order to be adopted by different shipyards. It allows the estimation of costs and help on the establishment of a schedule for the execution of the hull.

1 INTRODUCTION

The understanding of the cost structure of a given production process is always of high importance for the budgeting of a given work order. Only then it is possible to make the best budget approach so that a shipyard can be competitive in the middle of many others in the shipbuilding market (Deschamps & Trumbule, 2003).

Leal & Gordo (2017) make a budget breakdown, i.e., the decomposition of the total cost of the ship's hull construction in several smaller parts each one associated to a given cost centre, to evaluate the percentage of each of the cost centres that make up the final cost. Note that when talking about the ship's hull in this study, it implies the inclusion of its superstructure, but always excluding any appendices and outfitting.

There are already several computer programs available on the market that address effectively the budgeting of shipbuilding, taking advantage of large shipyards production databases, combined with analytical cost models and dividing the hull construction into several cost parcels. There is for instance the SPAR ESTIMATE that uses the PODAC model (Ennis, 1997), (Trumbule, 1999). On the other hand, it starts to be usual the development of own software tools at each shipyard that solve and analyse shipbuilding production costs (Bertram, 2004).

It is proposed to create tools that allow to make simple estimates, quick and realistic budgeting for a given ship work. These estimates are to be found by means of statistical analysis of shipbuilding processes times and costs of building several blocks of a ship.

These estimates can then vary for different types of blocks by an adjustment coefficient associated with block construction difficulty degree, i.e. having two blocks with similar weight we have different cost estimates for them according to the complexity of their construction.

Today the ship production scheme is oriented by the construction by blocks. This type of construction allows a faster production flow, with better quality, mainly due to the possibility of the inside covered areas construction, and also due to the application of production lines of the different production stages. One of basis of the block's manufacturing is the panel's line. The panel's line is a key phase of the construction of the block and an important production area in the shipyard.

The panel's lines were implemented in the European and Japanese shipyards in the 1960's, in order to respond to the increased demand of very large crude carriers (Cahill, et al., 2000). Since then, the panel's line was developing into a more flexible equipment, lower acquisition cost and higher productivity (Andritsos & Prat, 2000).

The characteristics of this construction stage make it very straightforward to apply the lean techniques, hence improving the production and its efficiency (Kolich, et al, 2016).

Therefore its analysis constitutes a strong basis for developing a block's cost tool that can afterwards be extended to ship's cost production.

2 COST MODEL TOOL

2.1 Cost structure

Any shipbuilding will always pass through the following phases (Van Dokkum, 2008) (Bachko & Hoffmann, 1980) with their respective associated costs:

- Contract signing
- Basic project
- Detail production project
- Ship hull construction
- Outfitting (piping, electricity, machinery and systems)
- Sea trials and certification
- Ship owner delivery

In between the above mentioned phases there will also exist stages of quality control, transportation, supervision and also plan approval from shipyard, marine design office, ship owner, classification societies and maritime flag authorities.

This cost model for manufacturing of the hull will solely focus on production phases (detailed engineering for production) and the phase of hull construction, except the union of blocks.

Within the construction phase of the hull, which is the main purpose of this study, one has the following steps:

- Parts, plates and stiffeners cut
- Plate union (bulkheads, floors and shell)
- Assembly and welding of frames and stiffeners to form panels and subsets
- Union of subsets to form ship blocks
- Union of blocks to form the whole ship

For each one of these costs centers the idea is to apply a generic formula of the following type:

$$C_{proc}\begin{bmatrix} Labour\ cost + Energetic\ cost + \\ +Consumable\ materials\ cost + \\ +Equipment\ cost \end{bmatrix}[\text{€}] \quad (1)$$

The energy cost represents the electricity spent with operation of equipment, materials costs are related to expenditures with supplies and materials used by the process and finally the equipment costs estimates the costs associated with the technologies involved in the process. These 3 referred costs tend to be lower than the labour costs.

2.2 Cost model tool

This section presents in a succinct way the cost model tool made on an EXCEL worksheet.

This tool is created from the results obtained during the study and intends to make quick cost estimates for a steel ship block steel work (Leal & Gordo, 2017).

On the main menu of the tool, shown in Figure 1, the user is allowed to select several settings for each cost center and adjustment coefficients of following activities: work's preparation, cutting processes, transportation and associated meanings, forming and assemblage of plates and stiffeners, used welding techniques. Complementary information about shipyard capabilities and material prices can be supplied.

In this worksheet it can be introduced the known parameters of the budgeted ship's block. Which are: the type of vessel, the location of the block along the vessel, overall dimensions and estimated weight. The complexity coefficients are automatically selected after choosing the type of vessel and block. There is an indicator of λ factor for verifying whether the dimensions of the analyzed block are within the limits of the case study examined in this paper.

In the main menu it is also possible to select the input data button that will lead to the data input screen visible in Figure 2.

Returning now to the main menu (Figure 1) you can choose the cost estimate results option. In this selected page (Table 1) it is possible to enter the identification name of the block. All other values and graphics presented are the result of immediate calculation, and therefore cannot be changed.

The result summary presents for instance the distribution of costs by each cost center. It also estimates the necessary man-hours, consumables amounts, required plates and stiffeners, etc. These results depend on the input data and also on the established settings.

This results output also includes some graphical information about partial costs (Figure 3) and man-power (Figure 4).

It is interesting to note that, for the case under analysis Leal, half of the total cost is with material and the second highest cost is the preparation of work.

2.3 Cost centres configuration

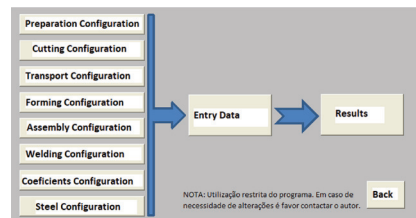The costs associated with work's preparation are configured for each shipyard as presented in Figure 5.

Figure 1.   Program's main menu interface.

Figure 2. Data input screen.

Table 1. Summary of costs estimate results.

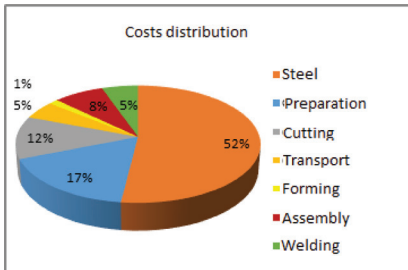Figure 3. Distribution of cost by activity.

Figure 4. Distribution of man-hours by activity.

The formulation of the cost is, according to Leal & Gordo (2017):

$$C_p = P_b \cdot \left(\gamma_b \cdot CER_p \cdot MDO_p + CEQ_p \right) [\text{€}] \qquad (2)$$

P_b – Block weight [t]
γ_b – Block complexity coefficient
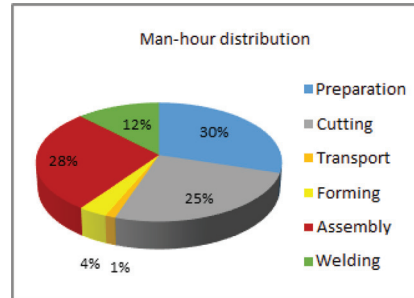CER_p – Work preparation cost estimate relationship [Mh/t]

CER$_{preparation}$	15	[h/t]
Required time of preparation	528,75	[Mh]
N.º of workers	4	[M]
Salary of workers	15	[€/h]
Equipament cost	50	[€/t]

Figure 5. Preparation costs.

MDO_p – Work preparation labour cost [€/Mh]
CEQ_p – Work preparation equipment costs [€/t]

The cutting costs of plates and stiffeners are configured for each shipyard as presented in Figure 6.

These costs are estimated in direct relation with the produced weight of steel variable according to the following simplified equation:

$$C_c = P_b \cdot \left(\gamma_b \cdot CER_c \cdot MDO_c + CC_c + CEQ_c\right) [€] \quad (3)$$

CER_c – Cutting cost estimate relationship [Mh/t]
MDOc – Cutting labor cost [€/Mh]
CCc – Cutting consumables cost [€/t]
CEQc – Cutting equipment costs [€/t]

The parameters for transport resources are configured for each shipyard as presented in Figure 7.

These costs are estimated relatively to the produced weight of steel variable in a simplified manner by the following equation:

$$C_t = P_b \cdot \left(\gamma_b \cdot CER_t \cdot MDO_t + CEQ_t\right) [€] \quad (4)$$

CER_t – Transport cost estimate relationship [Mh/t]
MDO_t – Transport labour cost [€/Mh]
CEQ_t – Transport equipment costs [€/t]

Figure 6. Cutting parameterization.

Figure 7. Transport resources parameterization.

The parameters for forming of a block are configured for each shipyard as presented in Figure 8.

These costs will be estimated according to the weight amount of processed steel in the following simplified equation:

$$C_e = P_b \cdot \left(\gamma_b \cdot CER_e \cdot MDO_e + CC_e + CEQ_e\right) \quad (5)$$

CER_e – Forming cost estimate relationship [Mh/t]
MDO_e – Forming labor cost [€/Mh]
CC_e – Forming consumables cost [€/t]
CEQ_e – Forming equipment costs [€/t]

The parameters for the assemblage of the block are configured for each shipyard as presented in Figure 9.

These costs are estimated once again according to the variable of steel weight to be produced in the following equation:

$$C_m = P_b \cdot \left(\gamma_b \cdot CER_m \cdot MDO_m + CC_s + CEQ_m\right) \quad (6)$$

CER_m – Assembly cost estimate relationship [Mh/t]
MDO_m – Assembly labor cost [€/Mh]
CC_s – Welding consumables cost [€/t]
CEQ_m – Assembly equipment costs [€/t]

The tool considers 3 types of welding: flux cored arc welding (FCAW), automatic FCAW, and submersed arc welding (SAW).

The parameters for FCAW welding are configured for each shipyard as presented in Figure 10.

Figure 8. Forming's parameterization.

Figure 9. Assemblage parameterization.

FCAW		
Percentage of usage	40	[%]
CER$_{weld}$	8	[h/t]
Required welding time	112,8	[hM]
N.º of welders	2	[M]
Average welder salary	9	[€/hM]
Welding speed	2,8	[m/h]
Price of 16 Kg reel	38	[€]
Reel weight	16	[kg]
Protection gas	2,5	[€/t]
Electricity	6	[€/t]

Figure 10.   Typical welding parameterization.

These costs are estimated for the produced weight of steel in the simplified equation:

$$C_s = P_b \cdot \left(\gamma_b \cdot CER_s \cdot MDO_s + CC_s + CEQ_s \right) \qquad (7)$$

CER_s – Welding cost estimate relationship [Mh/t]
MDO_s – Welding labor cost [€/Mh]
CEQ_s – Welding equipment costs [€/t]

2.4   Configuration of block's parameters

There are 8 available settings interfaces to configure initial parameters: Work preparation, cutting, transportation, forming, assembly, welding, steel and coefficients.

Table 2 shows the proposed complexity factors to be multiplied to the cost of each activity, according to the location of the block along the vessel.

The complexity factor is intended to compute the degree of complexity of each block in comparison to the standard one which is considered to be the block of a superstructure. The coefficient should be calculated by each shipyard according to historical data acquired in previous ships. Nevertheless, the coefficient should not very much from shipyard to shipyard because they represent basically the complexity of the structure.

It can also be adopted some adapted complexity coefficients associated with the type of vessel to be

built (Ennis, et al 1997), observed in Table 3. After analyzing the various case studies, it is proposed the following cost estimation relationships (CER) in accordance with the respective cost centers, as shown in Table 4.

Note that this study does not take into account the influence of the learning curve (Deschamps & Trumbule, 2003). However, it can be applied a discount on the number of hours spent on sister ships blocks building on the construction of large series of identical vessels. This happens due to the experience gained in construction methodology,

Table 2.   Complexity coefficients relatively to ship's block location along the vessel.

Complexity Coefficient

Superstructure	1,00
Bow	1,35
Bow (with Bulb)	1,45
Stern	1,35
Stern (with S*keg*)	1,45
Engine Room	1,50
Midship	1,10
Midship (Double Bottom)	1,25
Midship (Double Side)	1,25

Table 3.   Complexity Coefficients according to vessel's type.

Complexity Coefficient

Crude Oil Tanker	0,90
Product Tanker	1,13
Chemical Tanker	1,25
Bulk Carrier	0,86
OBO Carrier	0,95
Container Ship	0,96
RO-RO Ship	0,83
Ferry	1,25
Passenger Ship	3,00
Fishing Boat	2,20
Tug	0,80
Naval Research	1,25
Oceangoing Tug	1,00

Table 4.   Several proposed Cost Estimate Relationships.

	CER
Work Preparation	∂15 Mh/t
Cutting + Forming	∂36 Mh/t
Assembly + Welding	∂50 Mh/t
Work Preparation + Cutting + Transport + Forming + Assembly + Welding	∂100 Mh/t

Table 5. Example of cost adjustment coefficients in relation to the shipyard location.

Tuna Fishing Vessel of 31m LOA				
Final price [€]	Hull cost [€]	Mh [est.]	Cost [€/Mh]	Coefficient
Portugal (2011) 3 152 305	966 453		70.85	1
Spain (2011) 3 732 745	1 027 338		75.32	1.1
Croatia (2011) 2 571 865	693 653	13 640	50.85	0.7
China (2011) 1 933 381	393 573		28.85	0.4
Portugal (1995) 1 024 994	298 196		21.86	0.3

the simplification of some processes or even the change in some production design details.

Adjusting coefficients may still be related to where the ship is built, which basically takes into account the cost of labor in other countries than Portugal. The example shown in Table 5 compares quotation requested prices for the building of a 31 m fishing vessel taking into account different shipyards worldwide.

All these factors can be multiplied one with other in order to obtain a final value of the block complexity γ_b as discussed in (Leal & Gordo, 2017).

3 CONCLUSIONS

It is possible to divide the shipbuilding cost of a steel hull into 6 simplified parts, corresponding to different cost centres and through adjustment coefficients on the productivity of each process and complexity of implementing it, one can get corrected cost estimates.

Regarding the simplified formulas for calculating the costs for each production process described in this study, it appears that the most important variables are the labour costs and productivity associated with each process, which in turn is connected to the technology of the equipment used and the degree of qualification of the worker. The costs associated with supplies and equipment used in the production process are only a small portion of the total costs.

The created worksheet proves to be a very useful tool for the initial approach of the budgeting of a given shipbuilding steel work. It is customizable according to the coefficients of productivity of each yard and adjustable levels of complexity for each ship block type. It is also possible to update values of skilled labour and material costs.

ACKNOWLEDGEMENTS

REFERENCES

Andritsos, F., & Prat, J. (2000). The Automation and Integration of Production Processes in Shipbuilding, State-of-the-Art. European Commission Joint Research Centre.

Bachko, N.L., & Hoffmann. (1980). Shipbuilding Costing and Contract Arrangements. Em *Ship Design and Construction.* New York: The Society of Naval Architects and Marine Engineers.

Cahill, P., Shank, R., Crilly, P., Kelly, G., Jutla, T., & Weeks, T. (2000). Implementation of a State of the Art First Operations Shop in a Second Tier Shipyard. *Journal of Ship Production,*, 133–150.

Deschamps, L., & Trumble, J. (2003). Cost Estimating. Em *Ship Design and Construction* (Vol. 1). SNAME.

Ennis, K., Dougherty, J., Lamb, T., Greenwell, C., & Zimmermann, R. (1997). Product Oriented Design and Construction Cost Model. *Ship Production Symposium.*

Kolich, D., Storch, R., & Fafandjel, N. (2016). Optimizing Shipyard Interim Product Assembly Using a Value Stream Mapping Methodology. *World Maritime Technology Conference.*

Leal, M., & Gordo, J. (2017). Hull's Manufacturing Cost Structure. *Brodogradnja/Shipbuilding, 68*(3), 1–24. doi:10.21278/brod68301

Van Dokkum, K. (2008). *Ship Knowledge—Ship Design, Construction and Operation.* Dokmar: Maritime Publishers B.V.